EXPERIENCE FROM THE FIELD
Gastroenterology

Editing combined multichannel intraluminal impedance and pH monitoring tracings

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Multichannel intraluminal impedance (MII-pH) monitoring has become the gold standard for assessment of gastroesophageal reflux (GER) in infants, children, and adults. The primary advantage of MII-pH monitoring over pH monitoring alone is the ability to detect and quantify nonacid GER (pH ≥ 4). Multiple impedance channels along the length of catheter permit the monitoring of proximal movement of refluxed bolus within the esophageal lumen and the assessment of clearance efficiency. In addition to being able to measure the frequency and duration of refluxed boluses, one of the most important applications of the technology is the ability to assess the temporal relationships between all GER types with reported symptoms.

There are some challenges to the use of MII-pH monitoring. First, the MII-pH system is costly and therefore not available in every center. Second, operationalizing the execution, the analysis, and the interpretation of the studies all require considerable expertise. Third, considerable time commitment is required to generate an accurate and comprehensive analysis.

Several post-study modifications should be considered before the data can be analyzed and interpreted. While most users are aware that MII-pH tracings require editing, they may not be aware of all the editing that may be necessary for a given tracing.

The analysis of the MII-pH studies should be given sufficient time and attention to detail so that it can be relied upon for the development of appropriate clinical management strategies. The fact that MII-pH monitoring is moderately invasive, collects data for 24 h, and can lead to significant changes in clinical decision-making, should incentivize thorough editing to maximize the accuracy of the data extracted from each tracing.

EDIT TYPES

Editing types are divided into three groups (deletions, insertions, and miscellaneous) and are listed in Table 1.

1. Deletion edits

1. Many MII algorithms employ an autoscan that produces numerous false positives. These events need to be deleted by selecting the event and pushing the delete button. Supporting Information S1: Figure 1 illustrates an example wherein the algorithm has constructed a GER between two swallows.

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TABLE 1  Types of edits for impedance-pH tracings.

<table>
<thead>
<tr>
<th>Deletion edits</th>
<th>Insertion edits</th>
<th>Miscellaneous edits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. False positives</td>
<td>1. Fine-tuning the duration in the distal impedance channel (Z6) and the proximal extent of autoscan-tagged events</td>
<td>1. False negatives</td>
</tr>
<tr>
<td>2. Esophageal acidifications following a swallow</td>
<td>2. Separating GER events that were combined during autoscan</td>
<td>2. Additional symptom types not programmed into recorder box</td>
</tr>
<tr>
<td>3. Esophageal acidifications immediately before and after a meal</td>
<td>3. A written diary of events should be maintained during the study.3 When the study is completed, the diary should be examined and recorded events should be cross-referenced with those that were logged directly into the electronic diary.</td>
<td>3. A major part of the editing process is the “fine-tuning” of tagged (by autoscan) impedance events. There are two characteristics of an impedance-detected GER event that are important; the duration of the GER in the distal esophagus (Z6) and the proximal extent of the reflux event (does the reflux frequently approach the oropharynx and thus place the patient at increased risk of aspiration) Supporting Information S1: Figure 3 depicts a nonacid reflux event frequently approach the oropharynx and thus place the patient at increased risk of aspiration) Supporting Information S1: Figure 3 depicts a nonacid reflux</td>
</tr>
<tr>
<td>4. Slow pH-Drifts and pseudo-reflux</td>
<td>4. Separating GER events that were combined during autoscan</td>
<td>4. Slow pH drifts without impedance should be included for calculations of acid GER (AGER) index (percentage of time the esophagus is acidified by GER), they should not be considered individual GER episodes.</td>
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<tr>
<td>5. Periods of the study when impedance-pH channels flatline (signal loss)</td>
<td>5. Pseudo-reflux,10 indicated by the gradual decline of the pH waveform to &lt;pH 4 followed by a quick return to baseline, should also be deleted.</td>
<td>5. Periods of the study when impedance-pH channels flatline (signal loss)</td>
</tr>
<tr>
<td>6. GER that occurs during a meal but within a symptom window</td>
<td>6. A GER event that occurs during a meal and also within an overlapping 2-min symptom window, will be temporally associated with that symptom even though analysis settings are set to exclude meals.11 These GER events should be deleted so that they do not influence symptom-reflux correlations.</td>
<td>6. GER that occurs during a meal but within a symptom window</td>
</tr>
<tr>
<td>7. Multiple symptom records</td>
<td>7. Occasionally, a symptom button is pushed multiple times, within a short period, and ultimately produces an error (e.g., symptom association probability [SAP] = not a number [“NAN”]). We have found that, deleting all but one of the repeated symptom events within a 2-min window results in restoration of a numeric symptom assessment value. Others have suggested a 4-min window.7 An agreed-upon standard window for deleting duplicate/excessive symptoms has yet to be established. Further studies are needed to drive research-based decision-making regarding the deletion of repeated entries.</td>
<td>7. Multiple symptom records</td>
</tr>
<tr>
<td>8. Early portion of study following catheter repositioning</td>
<td>8. Occasionally, radiological confirmation of catheter placement shows that the catheter needs to be repositioned. Artifact markers are used to span the duration from when the study began to the time point at which the catheter is successfully repositioned.3</td>
<td>8. GER that occurs during a meal but within a symptom window</td>
</tr>
</tbody>
</table>

Abbreviation: GER, gastroesophageal reflux.
GER event in which the autoscan neglected to include the proximal-most waveform (Z1). The duration in any of the other channels is unimportant because they rarely are considered in the assessment report. The reflux duration in either channel is defined by the points of bolus entry (impedance waveform drops to <50% of baseline) and bolus exit (impedance waveform ascends to ≥50% of baseline).8
2. Occasionally, an impedance-detected reflux event will be tagged (by autoscan) as an obviously “combined” or “conjoined” event. This occurs when the impedance waveform in the distal channel never ascends to 50% of baseline before the second event occurs.12 To arrive at a more accurate inventory of reflux events (i.e., the number of transient relaxations of the lower esophageal sphincter), the analyst might consider separating the events as previously described.12

2 | DISCUSSION
When we train scientists and clinicians to work with MII-pH tracings, we generally focus on the identification and tagging of impedance-detected GER events. However, the reliability of the data extracted from a MII-pH tracing is dependent on comprehensive and thorough editing of the entire tracing. While the proper training and experience of the analyst is important, the quality of the instruction provided to the patient, constant attendant and/or parent/guardian is also critical.3

This paper outlines several types of editing that is recommended to ensure the accuracy of the extracted data. The most novel edit type is the importance of examining the borders of individual meals for meal-related acidification. Despite pre-test instructions to avoid acidic foods and beverages, the reality is that most patients are not aware of the pH of all foods/drinks; consequently, if they were to start to eat or drink before hitting the meal button or if they do not wait until the esophagus has neutralized to push the button again, one or both meal borders will be acidic.9 Left unedited, these meal-related acidifications could increase the AGER index to above threshold levels.

We expect that future improvements in the MII-pH software’s algorithm will reduce the time commitment for the analyst. Until then, thorough editing of MII-pH tracings is encouraged to correct for inherent low specificity, improve the accuracy of the data analysis and ultimately lead to good clinical outcomes. Also, with these MII-pH edits in mind, there can be a reduction in the relatively high intra- and interobserver variability.2

CONFLICT OF INTEREST STATEMENT
The authors declare no conflict of interest.

REFERENCES
12. Woodley FW. Superimposed non-acid reflux event: an example of when it may be important to revisit the impedance analysis guidelines. *J Neurogastroenterol Motil*. 2022;28(1):165-166.

SUPPORTING INFORMATION
Additional supporting information can be found online in the Supporting Information section at the end of this article.

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